Large, Synoptic and Meso Scale Variations of the Baiu Front, during July 1982

Part I: Cloud Features

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Abstract

The large, synoptic and meso scale features of the Baiu front that occurred during July 1982 are described, based mainly on GMS-IR digital data. The periods of synoptic and meso scales were determined by spectral analysis of the cloud amounts in the Baiu front. Attention was focused on three subjects: (1) the large-scale (5-day mean) features during the active phase of the Baiu front, (2) the difference of synoptic-scale (having a period of about six days) and mesoscale (a period of a few days to one day) variations in cloud features occurring over the continent (the western part of the Baiu front) from those occurring over the NW Pacific (the eastern part) and (3) the difference in frontal activity between 00GMT and 12GMT.

During the active phase characterized by large cloud amounts in the 5-day mean, large-scale baroclinicity, low-level southwest to west-southwest wind found south of the frontal zone, moisture flux convergence and the horizontal gradient of equivalent potential temperature (θ_e) in the lower layer of the frontal zone are strong, compared with those found during the inactive phase.

The large-scale features around the frontal zone over the continent differ from those over the NW Pacific. These regional differences in the large-scale features are reflected in the synoptic and meso scale cloud features in the frontal zone.

Over the continent where the frontal zone is characterized by a strong low-level wind and an air mass of high θ_e , the synoptic-scale and mesoscale variations are prominent. The mesoscale cloud clusters that develop with a one-day period have diameters of ~ 500 km and consist of convective clouds. Over the continent, the one-day period variations of clouds are related to the underlying topography; mesoscale cloud clusters tend to develop in the basin areas around 00GMT and in the high altitude regions around 12GMT. There was hardly any meander of the frontal zone with a synoptic-scale period.

Over the NW Pacific where the Baiu front is characterized by baroclinicity and an air mass of rather lower θ_e , the frontal zone meanders with a synoptic-scale period. The mesoscale cloud clusters that compose the synoptic-scale cloud systems are relatively large (~ 1000 km) and develop having periods of a few days. The mesoscale clusters consist of areas of narrow convective and wide stratiform clouds. In the frontal zone over Japan, both synoptic and meso scale variations show transitional features from those over the continent to those over the NW Pacific.

Over the continent, the Baiu frontal cloud zone shifts north about 200 km around 00GMT. The shift is associated with the increase in the low-level moisture flux south of the frontal zone, the increases in the low-level moisture flux convergence and middle-level moisture content in the frontal cloud zone.

In Part II of this study, the structure of the Baiu front and features of synoptic and meso scale Baiu frontal disturbances will be clarified by analysis of relative vorticity fields.

1. Introduction

The Baiu front is a stationary front formed over East Asia during the summer monsoon season. The Baiu frontal activity brings large amounts of rain to China and Japan during June and July. Clarification of the large-scale features of the Baiu (termed the Mei-yu in China) front have been made in several recent papers (*e.g.*, see Luo and Yanai, 1983, 1984; Murakami and Huang, 1984; Ninomiya, 1984; Kato, 1985; Ninomiya and Muraki, 1986). These papers emphasized the portion of the Baiu front found over the China region and revealed characteristics such as the low-level wind field, water-vapor transport and thermal gradient. From the heat and moisture budget analyses in their studies it was found that the Baiu front is a zone of active convection. However, neither detailed features of cloud/rainfall in the Baiu front nor the differences of large-scale features between the active and inactive phases of the Baiu front have been fully described in these papers.

Utilizing polar-orbiting satellite mosaic brightness pictures, Akiyama (1973) studied the large-scale aspects of cloud and rainfall features of the Baiu front, mainly over the East China Sea to the Japan Islands. However, prominent space-time scales of cloud variations in the Baiu front and their characteristics, along with small scale cloud features in the frontal zone were not described. In order to further understand the frontal cloud features, it will be necessary to examine various scales of cloud variations over the entire frontal zone from Continental China to the Northwest Pacific, utilizing more reliable data.

During the 1970's, several authors focused their attention on the small-scale (meso- α and meso- β scales) variations of the Baiu front over the Japan Islands (*e.g.*, see Ninomiya and Akiyama, 1972, 1973; Yoshizumi, 1977; Akiyama, 1978). It was found that the Baiu front in this region consisted of a row of meso- α scale cloud clusters which were made up of a few meso- β scale radar echoes. The kinematic and thermal structure of the clusters were also discussed. On the other hand, with respect to convective activity over the China region during a summer monsoon season, Murakami and Huang (1984) by use of a comosite method investigated the evolution of small-scale cyclones which developed in central China and brought about local rainfall. In their study, however, the relationship between the cyclones and the Baiu frontal zone was not clearly described.

Ninomiya *et al.* (1981) made a more detailed study of a meso- α scale cloud cluster which was generated at the eastern foot of the Tibetan Plateau and propagated to the Japan Islands along the Baiu frontal zone. They found that the cloud features of the cluster changed over the East China Sea where the

structure of the Baiu front also changed. Akiyama (1984 a, b) made a more detailed analysis of the same case and found that the cluster consisted of convective clouds over the continent while it consisted of both stratiform and convective clouds over the Japan Islands. They also pointed out a diurnal cycle in the development of the cloud cluster.

The purpose of this paper is to describe the space-time variations of the Baiu front during July, 1982, on the basis of Geostationary Meteorological Satellite Infrared (GMS-IR) data. Interest in Part I is focused on the following three subjects:

- (1) the difference of large-scale features between the active and inactive phases of the Baiu front.
- (2) the difference between frontal activity over the western part (the China Continent) and over the eastern part (the NW Pacific) of the Baiu front.
- (3) the difference between frontal activity at 00GMT and 12GMT.

Data acquisition and analysis procedures are described in Section 2. A general survey through the analysis period will be made in Section 3. In Section 4, large-scale variations will be discussed based mainly on the 5-day mean fields. Synoptic and meso-scale variations will be examined in Sections 5 and 6, respectively. Section 7 will present remarks and comments for further study.

In a companion paper, Part II of this study, the structure of the Baiu front and features of synoptic-scale and mesoscale disturbances in relation to Baiu frontal activity, are described by analysing vorticity fields.

2. The analysis period and data

In normal years, heavy rainfalls occur during the last stage of the Baiu season (the end of June and the beginning of July) over Japan. The onset and end of the 1982's Baiu in Japan were delayed by one-two weeks as compared with normal years (Long-Range Forecast Data, NO 8212, JMA). Heavy rainfall associated with the 1982's Baiu occurred during 10–30 July over the main parts of Japan. This period includes the case of torrential rains which occurred at Nagasaki Prefecture in Kyushu (Southwest Japan) on 23 July (Ninomiya *et al.*, 1984; Ogura *et al.*, 1985). For these reasons, July of 1982 was chosen for the analysis period.

The analysis period is divided into six 5-day sub-periods (Table 1), Period 1–Period 6 in this paper. Use will be made of the scale definitions found in Table 2 of this paper, which were determined based on the spectral analysis of high-cloud amounts (Ch) as presented in Section 5.

Table 1. Subdivision of the analysis period and classification

Period 1	01 – 05	JUL 1982	T.D.
Period 2	06 – 10		inactive
period 3	11 – 15		active
Period 4	16 – 20		active
Period 5	21 – 25		active
Period 6	26 – 30		inactive

Table 2. Explanation of the time-scales used in this paper.

large-scale	longer than about 6 days
synoptic-scale	about a 6-day period
mesoscale	one to a few days period

The data used are as follows:

1) The GMS-IR digital data. Use is made of two kinds of GMS-IR data reduced by the Meteorological Satellite Center, JMA. One is the high-cloud amount (Ch) in 1° latitude by 1° longitude areas, which is defined as the ratio of the number of pixels with black body temperature (TBB) lower than the temperature at the 400 mb level to the total number of pixels in the area. The other is the mean of the TBB, averaged over the 1° latitude by 1° longitude area, eliminating TBB higher than some critical value which indicates sea/ground surface TBB. In essence, the mean TBB is the average for the TBB in the cloud part of the area. These GMS data are given at 12-hour intervals in this paper. The domain of the GMS data analysed covers the area of 90°E – 170°E and 50°N – 20°N .

2) The AMeDAS precipitation data: For rainfall analysis over the Japan Islands, hourly Automated Meteorological Data Acquisition System (AMeDAS) data at 1276 gage stations are used. The average distance between the gage stations is about 20 km.

3) The FANAL data: The grid point values of Fine-mesh Analysis (FANAL) data at mandatory pressure levels, prepared by the operational fine-mesh objective analysis system of the Numerical Prediction Division, JMA, are used in the present paper. The grid distance between FANAL data points is about 254 km at 60°N latitude on a polar stereographic projection map. The analysis domain is shown in Fig. 1.

3. Rainfall features over Japan

To survey Baiu frontal activity during the analysis period, rainfall features over the main parts of Japan are investigated. Fig. 2 shows the time variations of the 3-hour areal mean rainfalls over the six Areas (defined in the left panel of Fig. 2) during the

Fig. 1. Analysis domain of the FANAL data used in this paper. GMS data are analysed over the region bounded by the stippled frame. Mountain areas higher than 3000 m are shown as black.

30-day analysis period. This figure represents rather well the rainfall features during the last stage of the Baiu season in Japan. The Baiu front (the zone of maximum cloudiness) in period 1 was located south of Japan (Fig. 3) and rainfall over Japan was slight. The Baiu front for Period 2 through Period 5 lay almost stationary over the main Islands of Japan, and rainfall was heavy through these periods, occurring most frequently in southwestern Japan (Area 6). For Period 6, when the Baiu season was nearing the end, the area of heavy rainfall moved north with the northward movement of the frontal zone. As a whole, rainfall amounts were very large in southwest Japan (Area 6) and decrease toward the northeast (Area 1). The maximum rainfall reached ~ 20 mm/3h in Area 6, while it was ~ 5 mm/3h for Area 1.

Attention will be focused on the periodic variations of the rainfall. Heavy rainfall in the southwestern half of Japan (Areas 4, 5 and 6) occurred with periods of one to a few days during Period 2 through Period 5. On the other hand, light rainfall occurred having about a six-day period in northern Japan (Areas 1 and 2). As will be described in Sections 5 and 6, heavy rainfall with a period of one to a few days were related to mesoscale cloud clusters, while the rainfall with periods of about six days corresponded to synoptic-scale variations in cloudiness. The occurrence time of rainfall peaks was delayed toward the northeast. To summarize, the variation of rainfall in southwest Japan is characterized by mesoscale and heavy rain and that in northeast Japan by synoptic-scale and light rain. These features were most evident during Periods 3 and 4. The differences of rainfall features among the areas indicate the differences of Baiu frontal activity between the western and eastern part of Japan and between

Fig. 2. Time series of 3-hour areal mean rainfall during the analysis period for the Areas (1-6) shown on the left part of the figure.

the southern and northern half of the frontal zone.

4. The large-scale variation of the Baiu front

Large-scale variations of clouds in the Baiu front are investigated by use of the 5-day mean fields, in relation to the variation of the large-scale features. Attention is focused on the differences of large-scale features between the active and inactive phases of the Baiu front and between 00GMT and 12GMT.

a. Cloud distributions

Overall, the zone of cloud amount of more than 20 % extended east to west over the 30°N–40°N latitude zone throughout Period 1 through Period 6 (see Fig. 3).

This zone of maximum cloudiness is defined as the Baiu front or the frontal zone in this paper. The zone moved from around the 30°N latitude circle in Period 1 to the 40°N latitude circle in Period 6, fluctuating north and south with synoptic-scale periods. This northward movement of the Baiu front with a phase speed of about 1000 km/month is accompanied by the change of the global circulation. The northward movement of the Baiu front is evident between 90°E and 140°E. The change over the China Continent and the adjacent ocean regions is greater than that over the Northwest Pacific. Cloud amounts are generally large over the continent as compared with the Pacific. During Period 1 through Period 6, the clouds spreading north of the Baiu frontal zone are accompanied with upper synoptic-scale cut-off lows and/or troughs, as will be noted in Section 5.

During Period 1, the cloud zone ($Ch > 20\%$) was found from $\sim 30^\circ\text{N}/160^\circ\text{E}$ extending to the west-southwest. Period 1 is characterized by Baiu frontal activity interacting with a tropical depression with the large cloud amounts around 20°N – 25°N and 110°E – 120°E mainly due to the high clouds of this tropical depression. In Period 2, the cloud zone also extended from ENE to WSW, but the cloud amounts associated with it were rather small, especially east of around 140°E . Periods 3, 4 and 5 show the cloud zone as almost zonal, extending along the 30°N latitude circle with large cloud amounts, especially in Period 4 when areas of cloud amounts of more than 80 % were widely found. In Period 6, the cloud zone over the China Continent lay further north, compared with Period 5, and a cloud zone associated with the ITCZ appeared over the southern part of the continent and the adjacent ocean regions. From these cloud features, Periods 2 and 6 are defined as inactive phases, while Periods 3, 4 and 5 are considered active phases of the Baiu front (Table 1). Fig 3 also shows the difference in the high cloud distribution between 00GMT and 12GMT. This aspect will be discussed in Subsection 4-f.

b. 500 mb height and temperature fields

Fig. 4 shows the large-scale features over East Asia along with areas of Ch of more than 40 % for each period. A ridge remained over $\sim 60^\circ\text{N}/120^\circ\text{E}$ throughout most of the analysis period. The east-west axis of the western Pacific subtropical high was located approximately along the 20°N latitude circle in Period 1. After fluctuating north and south

Fig. 3. 5-day mean high-cloud amounts (Ch) for Periods 1-6. The figures on the right are for 12 GMT and the left are for 00GMT. The Isoline interval is 20 %. Shaded and black areas represent Ch of more than 40 % and 80 %, respectively.

Fig. 4-a. 5-day mean heights at the 500 mb level at 00GMT for Periods 1-6. The contour interval is 20 gpm. Black indicates areas where the 5-day mean Ch is more than 40 %.

during Period 2 through Period 5, the axis reached the 30°N latitude circle in Period 6.

The polar frontal zone (the zone of maximum ∇Z) found along the 50°N latitude circle, was clearly separated from the Baiu frontal cloud zone during Periods 1 and 2. A large-scale low with an associated polar air mass (Fig. 4-b and Fig. 6) centered at ~60°N/100°E during Period 1 moved slowly to

the southeast and intensified during Periods 2 and 3. It was located at ~45°N/130°E in Period 4, and had weakened considerably. It then moved northeast to the Sea of Okhotsk. The polar frontal zone moved south with the southeastward movement of the large-scale low, and was located close to the Baiu frontal cloud zone during Periods 3 and 4. As the low was weakening, the polar frontal zone gradually

Fig. 4-b. As in Fig 4-a, but for temperature. The isotherm interval is 1°C .

dissipated, and another polar frontal zone appeared in Period 5 around 80°E – 110°E along the 50°N latitude circle. However, the polar frontal zone became obscure in Period 6, while a blocking high developed around $50^{\circ}\text{N}/120^{\circ}\text{E}$. The large-scale features of Period 6 are similar to the middle summer conditions over East Asia in 1979, described by Ninomiya and Muraki (1986).

Next, the large-scale features around the Baiu frontal zone are examined. The Baiu front is formed

along the northwest edge of the Pacific subtropical anticyclone. During Periods 3, 4 and 5 a relatively strong height gradient (∇Z) is found around the Baiu front, compared with Periods 2 and 6. The strong ∇Z was caused by the southward movement of the large-scale low and the northward movement of the subtropical high. As would be expected, in Periods 3, 4 and 5 the temperature gradient (∇T) at 500 mb was also relatively strong around the Baiu front. From this it was concluded that when

the baroclinicity is relatively strong, cloud amounts along the front are relatively large. In other words, the active phase of the Baiu front coincides with a period of strong baroclinicity, which is controlled by the large-scale circulation. The large-scale features to the north of the frontal zone varied with periods. In Periods 1, 2, 5 and 6, short-wave oscillations are found. These oscillations caused an approximate 6-day period in the cloudiness along and just north of the Baiu front (Section 5).

With a precise examination of the baroclinicity along the Baiu front, it was found that east of $\sim 140^\circ\text{E}$ the front is characterized by baroclinicity throughout the analysis period, while west of 110°E it was characterized by very weak baroclinicity throughout the analysis period. The position of the transitional zone between the baroclinic zone over the Pacific and the weak-baroclinic zone over the continent shifted over the periods between 110°E and 140°E . In Periods 3 and 4, the transitional zone is found between 120°E and 140°E , while during Period 5 it was between 110°E and 130°E . These regional differences in the Baiu frontal structure in the present case (July 1982) are identical with the results of the case study for July 1979 by Akiyama (1984 a, b). As will be noted in Sections 5 and 6, the difference in the baroclinicity of these regions affects the synoptic-scale and mesoscale cloud features of the Baiu front.

c. 700 mb wind field

The large-scale features in the lower layer were examined by use of the 700 mb wind fields (Fig. 5). The cloud zone of the Baiu front was formed just north of the low-level jet axis which was oriented SW to WSW from the continent to the Pacific throughout the analysis period. The Baiu front coincided well with the zone of positive relative vorticity in the lower layer. The large-scale flow patterns north and south of the Baiu frontal zone changed from period to period. In general, when the SW-WSW wind located south of the frontal zone was strong, the cloud amounts in the frontal zone were large.

First, the flow pattern south of the Baiu front in the following three longitude zones will be described.

(1) 90°E – 110°E : The Baiu frontal zone around the eastern part of Tibetan Plateau (90°E – 110°E) was mainly influenced by SW-WSW winds from the Indian monsoon region.

(2) 110°E – 130°E : Strong SW-WSW winds along the Baiu front were formed by confluence of the S-SW wind from the Indian monsoon region and the SE-S wind from the western periphery of the Pacific subtropical anticyclone. The SE-S wind was strong during Periods 3 and 4 (active phases), compared with the S-SW wind, while the S-SW wind was stronger during Period 5 (an active phase) than the SE-S wind. There are two types of active phase

of the Baiu front. One is mainly due to the S-SW flow from the Indian monsoon region and the other is due to the SE-S wind from the west Pacific region. From this it is inferred that the detailed features of cloud, rainfall, frontal disturbances and frontal structures should be different between the two types of low-level flow pattern. However, the differences were not clear in the present case. To explore these differences other case studies should be examined in the future.

(3) 130°E – 150°E : The Baiu front east of $\sim 130^\circ\text{E}$ is active due mainly to a SW-WSW wind along the northwest edge of the Pacific subtropical anticyclone. Akiyama (1975) has pointed out, analysing the 4-day mean water budget over the Japan Islands during the active Baiu season of 1972, that low-level SW-WSW winds caused heavy rainfall over the Japan Islands and low-level SE-S winds which were flowing transversely into the Baiu frontal zone caused extremely heavy rainfall. It should be noted that there is a very active phase of the Baiu front associated with a strong low-level SE-S wind, although it was not found in July 1982.

Although the flow pattern south of the Baiu frontal zone is similar to that of Ninomiya and Muraki (1986), the flow pattern north of the front is significantly different from their case (July 1979). The "Baiu trough" with the north-northeasterly wind as they pointed out were not found in the present case. Instead, the southward movement of a large-scale cold vortex accompanied by the polar front, an associated WNW-NW wind along the north edge of the Tibetan Plateau and the confluence of the WNW-NW wind with the SW-WSW wind in the Baiu front, are pointed out as the noteworthy features of the present case. Large-scale cold vortexes like the present one are not normally found in July. The development of the anomalous cold vortex can explain the unusual Baiu season of 1982 (see Section 1).

d. 850 mb equivalent potential temperature

Air masses found in Fig. 6 were classified mainly by referring to Saito (1966). The pattern of the equivalent potential temperature (θ_e) maps is similar to that of mixing ratio maps (not shown here). The monsoon air mass ($\theta_e > 340\text{K}$) centered at 20°N latitude was widely spread from the continent to the adjacent ocean throughout the analysis period. In the higher latitudes, the polar air mass covered the North Pacific and Siberia. The relatively high θ_e (320 – 330K) mid-latitude air mass with a stagnant ridge protruded northward around 130°E . In the region between the 30°N and 50°N latitude circles, the distribution of air mass changed from period to period with changes in the positions of the polar front, the large-scale low and the Baiu front. The polar air mass protruding south to Japan during Period 1

Fig. 5. 5-day mean wind vector at the 700 mb level at 00GMT for Periods 1–6. A wind arrow length equal to one-grid size indicates 8 m/sec. Black areas are mountains higher than 3000 m.

retreated northward during Period 2, and the tropical air mass spread to the north with the northward movement of the Baiu frontal zone. Another polar air mass centered at $\sim 60^\circ\text{N}/100^\circ\text{E}$ during Period 2 extended to the southeast during Period 3 with the southeastward movement of the large-scale low. After the polar air mass moved eastward during Period 4 and to the northeast during Period 5, the mid-latitude and tropical air masses spread north-

ward over the continent and Japan. During Period 6, the tropical air mass spread farther north with the northward movement of the Baiu frontal zone. The large-scale thermal conditions in the lower layer for Period 6 shows the basic features of the mid-summer in East Asia as noted by Ninomiya and Muraki (1986).

The horizontal gradient of θ_e ($\nabla\theta_e$) was strong in the region of large cloud amounts of the Baiu front.

5-DAY MEAN θ_e 850MB

Fig. 6. 5-day mean equivalent potential temperature, θ_e , at the 850 mb level at 00GMT for Periods 1–6. The isotherm interval is 5°K . Stippling indicates areas of polar ($\theta_e < 320\text{K}$) air mass. Thin and dense hatched areas are tropical ($330\text{K} < \theta_e < 340\text{K}$) and monsoon ($\theta_e > 340\text{K}$) air masses, respectively. Areas bounded by the 320K and 330K isotherms represent areas of mid-latitude air mass. Black indicates mountain areas higher than 1500 m.

Especially over the continent during Periods 3 and 4, $\nabla\theta_e$ was very strong and θ_e on the south side of the frontal zone reached $\sim 350\text{K}$. On the other hand, $\nabla\theta_e$ east of $\sim 140^\circ\text{E}$ was relatively weak and θ_e on the south side of the frontal zone was also relatively low ($\sim 340\text{K}$), compared with those over the continent. The Baiu front over the continent is formed between the monsoon air mass and the

mid-latitude air mass, while the Baiu front over the NW Pacific is formed between the tropical and polar air masses. The Baiu front over the Japan Islands can be characterized as a transitional zone between the Pacific Baiu front and the continent Baiu front. These differences in the low-level thermal field over the Pacific and the continent are reflected in the differences in the cloud/rainfall features of the Baiu

frontal zone in both regions, as will be stressed in the following sections.

It is important that the active phase of the Baiu front is confined in the period of certain large-scale/synoptic-scale conditions, although the warm moist unstable air mass was widely spread south of the Baiu front throughout the analysis period.

e. The difference of 850 mb moisture flux between active and inactive phases

A large-scale SW-WSW moisture flux is found to the south of the Baiu frontal zone, east of $\sim 100^\circ\text{E}$ throughout the analysis period (not shown). The cloud zone of the Baiu front coincides with the zone of large moisture flux convergence ($\nabla \cdot q\nu < 0$). The moisture flux convergence was mainly accomplished by the SW-WSW moisture flux just south of the frontal zone throughout the analysis period.

Fig. 7 shows examples of low-level moisture flux during active (Period 4) and inactive (Period 2) phases. The greatest difference between the two periods is found in the magnitude $|q\nu|$ and horizontal convergence ($\nabla \cdot q\nu < 0$; the lower figures in Fig. 7) of the moisture flux around the frontal zone. During Period 4, a large moisture flux south of the Baiu frontal zone with a large moisture flux convergence in the frontal zone is found. For Period 2, the SW-WSW moisture flux is small, moreover, a portion of the moisture flux flowed north to the polar frontal zone, located around the 50°N latitude circle.

As seen in Fig. 6, South China and the adjacent ocean were covered by the monsoon air mass throughout the analysis period. The difference in features of the moisture flux between the active and the inactive phases lies mainly in the difference of the wind velocity. In essence, the low-level wind south of the frontal zone is the main factor directly controlling the activity of the Baiu front. In addition, the WNW moisture flux associated with the cyclonic circulation on the north side of the Baiu frontal zone converged with the SW-WSW moisture flux from the south of the Baiu front around 130°E during the active phase (Fig. 7). The strong low-level moisture flux convergence, in a large-scale sense, was basically caused by the development of the subtropical high and the southward movement of the large-scale cold vortex, as previously noted. In this context, the activity of the Baiu front is controlled by the overall large-scale circulations over East Asia.

f. The difference of low-level moisture flux between 00GMT and 12GMT

Low level moisture flux around the Baiu front, especially south of it, is larger at 00GMT than at 12 GMT throughout the analysis period (not shown). The differences between 00GMT and 12GMT are examined from a large-scale viewpoint in more detail.

During Periods 3, 4 and 5, the Baiu frontal zone

was formed at nearly the same position and cloud amounts were large (active phases). To examine the difference in the 850 mb moisture flux between 00GMT and 12GMT, 15-day means of the moisture flux were calculated over the three periods at 00GMT and 12GMT, and the difference in them was computed (Fig. 8). Large moisture flux was found at 00GMT in the frontal zone and to the south of it. The maximum value of $14 \times 10 \text{ g/kg m/s}$ was found just south of the frontal zone at 00GMT. At 12GMT, the region with a moisture flux of more than $10 \times 10 \text{ g/kg m/s}$ has decreased (not shown). The large difference of more than $5 \times 10 \text{ g/kg m/s}$ was observed south of the frontal zone over the continent and the adjacent ocean. The 850 mb moisture field at 00GMT was approximately equal to that at 12GMT. The difference of the moisture flux is mainly due to the difference in the wind. The large difference in the 850 mb wind field is found to the south of the Baiu frontal zone over the continent. The difference in the wind speed of the SW-WSW flow reaches 5 m/sec (not shown). Luo and Yanai (1983) and Akiyama (1984 a) have also pointed out the large difference in the low-level wind fields between 00GMT and 12GMT for the 1979 case.

The larger moisture flux along the frontal zone at 00GMT resulted in the larger moisture flux convergence ($\delta \nabla \cdot q\nu < 0$, see the right side of Fig. 8) in the Baiu front. Fig. 9 shows the field of the 15-day mean 500 mb mixing ratio q_{500} at 00GMT and 12GMT. In the Baiu frontal zone over the continent ($32^\circ\text{--}33^\circ\text{N}$, $110^\circ\text{--}125^\circ\text{E}$), q_{500} at 00GMT is larger than that at 12GMT. The larger moisture flux convergence in the lower layer of the Baiu frontal zone at 00GMT accounts for the larger moisture at 500 mb through vertical transport.

Next, the difference in cloud amount between 00GMT and 12GMT was examined. The top panel in Fig. 16 (Subsection 6-c) presents the 15-day (Periods 3, 4 and 5) mean δCh ($= \text{Ch}_{00} - \text{Ch}_{12}$). It is evident that Ch has increased on the northside of the Baiu front at 00GMT, but decreased in the southside. In other words, the zone of maximum cloudiness moves $\sim 200 \text{ km}$ northward between 110°E and 125°E at 00GMT as compared with that at 12GMT. It is interesting to note that the increases in the southwesterly flow (ν), the southwesterly moisture flux south of the Baiu front, the increase of moisture flux convergence along with the 500 mb moisture in the Baiu front and the northward shift of the zone of the maximum cloudiness occur at the same time. The physical processes and mechanisms of the above changes are not known at present. Murakami (1983) has shown, based on GMS-IR data, that the convective activity over the continent of South Asia during the summer monsoon season reaches a maximum at $\sim 18\text{LST}$ ($\sim 10\text{GMT}$). The relationship between Murakami's conclusion and that of the present study

5-DAY MEAN MOISTURE FLUX & FLUX CONVERGENCE

Fig. 7. Examples of the low-level moisture flux qv for the inactive and active phases. The figures on the right are for an active phase (Period 4) and the figures on the left for an inactive phase (Period 2). The upper figures are absolute values of 5-day mean moisture flux $|qv|$ at the 850 mb level at 00GMT. The isoline interval is 2×10 g/kg m/sec. Areas of moisture flux greater than 10×10 g/kg m/sec are stippled. The middle figures are the 5-day mean moisture flux qv at the 850 mb level at 00GMT. An arrow length equal to one-grid size indicates the moisture flux magnitude of 8×10 g/kg m/sec. The lower figures are the 5-day mean moisture flux convergence ($\nabla \cdot qv < 0$) at the 850 mb level at 00GMT. The isoline interval is 20×10^{-6} g/kg/sec. Stippled areas represent moisture flux convergence greater than -20×10^{-6} g/kg/sec. Black areas are mountains higher than 1500 m.

15-DAY MEAN MOISTURE FLUX & FLUX DIVERGENCE

Fig. 8. 15-day (Periods 3, 4 and 5) mean moisture flux qv (left) and moisture flux divergence $\nabla \cdot qv$ (right) at the 850 mb level for 00GMT (upper) and 12GMT (middle). An arrow length equal to one grid size represents a moisture flux magnitude of 8×10^{-6} g/kg/sec. The isoline interval (right) is 20×10^{-6} g/kg/sec. Stippled areas represent moisture flux convergence greater than -20×10^{-6} g/kg/sec. The lower figures are 15-day mean differences of moisture flux (left) $\delta qv = (qv_{00} - qv_{12})$ and moisture flux divergence (right) $\delta \nabla \cdot qv = (\nabla \cdot qv_{00} - \nabla \cdot qv_{12})$ between 00GMT and 12GMT. An arrow length equal to one grid size represents a difference moisture flux δqv magnitude of 4×10^{-6} g/kg m/sec. Black areas are mountains higher than 1500 m.

Fig. 9. 15-day (Periods 3, 4 and 5) mean mixing ratio q_{500} at the 500 mb level for 00GMT and 12GMT. Stippling indicates areas of mixing ratio greater than 4 gr/kg.

should be examined in more detail in future studies.

5. The synoptic-scale variation of the Baiu front

First, prominent periods of cloud variations in the Baiu frontal zone will be shown by examining the results of spectral analysis. To do this, spectral analysis was applied to high-cloud amounts averaged over areas of 2° latitude by 2° longitude for the 30-day analysis period. Fig. 10 shows the period-longitude diagram of spectral density in the 34° – 36° N latitude zone. Areas of high-spectral density are found periods of around 6 days, 3.5 days, 2.5 days, 1.5 days, 1.3 days and 1.0 day. As noted in Table 2, the variations with an approximate 6-day period were defined as synoptic-scale in the present paper, while the variations with periods shorter than a few days are defined as mesoscale. Fig. 11 displays the latitude-longitude diagrams of spectral density for periods of 5.86 days (top), 2.41 days (middle) and 1.00 day (bottom). Examination of the 5.86-day period diagram shows that areas of high-spectral density extending along the 30° N latitude zone coincide with the Baiu frontal cloud zone. In this section, the vari-

ation with the period of ~ 6 days in cloud distribution of the Baiu front will be described in association with synoptic-scale variations in the height fields.

In the following, use was made of TBB data, for the following reasons: the fine structure in the Baiu frontal cloud zone can be revealed by TBB maps, since TBB maps show more detailed variations in the 100 %-Ch areas. Also, the -20°C isotherm of TBB corresponds approximately to the 60 % isoline of Ch. On the average, the cloud zone of the Baiu front is found at about 30° N latitude over the continent, about 35° N over Japan and about 40° N over the Pacific ocean, during the analysis period (Fig. 3). Fig. 12 shows time-longitude sections of the TBB and 500 mb heights. From the TBB time sections at 30° N, 35° N and 40° N, it can be seen that several areas of TBB lower than -20°C propagated from west to east with an approximate 6-day period, with an eastward propagation speed of approximately 10° longitude/day. Nitta (1983) has shown that there was a peak in the power spectrum at a 6-day period, in the spectral analysis of the heat source in Eastern Tibet for the summer monsoon season of 1979. Although the physical relationship between the generation of synoptic-scale disturbances and the variation in the heat source is not clear, it is pointed out that the synoptic-scale (~ 6 -day period) cloud variations are commonly observed in the mid-latitude (30° N– 40° N) of East Asia during the summer monsoon season.

Fig. 13 shows the TBB time-latitude sections during the analysis period. Over the continent (95° E to 120° E), the Baiu frontal cloud zone formed along the 20° N latitude circle for Periods 1 and 2, moved northward to the 30° N latitude circle for Periods 3, 4 and 5 with the change in the large-scale circulation. The meander of the cloud zone associated with the synoptic-scale period is not evident over the continent, while synoptic-scale variations are evident between 40° N and 50° N latitudes over the continent (see Fig. 11). The Baiu frontal cloud zone east of 120° E begins to meander with the synoptic-scale period. The amplitude of the meander increases toward the east. The synoptic-scale variations of the Baiu front are very evident over the Northwest Pacific (150° E, 155° E, 160° E and 165° E of Fig. 13-c). As was noted in Section 4, the Baiu front over the continent is characterized by a strong low-level SW–WSW wind and weak baroclinicity, while the Baiu front over the NW Pacific is characterized by baroclinicity. The Baiu front around Japan is a transitional zone between the two regions. The differences in the frontal characteristics of these regions are reflected in the differences in features of synoptic-scale cloud variations as shown in Figs. 11 and 13.

Next, the 500 mb height changes in Fig. 12 will be examined. A large-scale low can be found propagating slowly eastward in the 50° N latitude zone. The

Fig. 10. Period-longitude section of power spectral density of high-cloud amounts (Ch) averaged over 2° latitude by 2° longitude areas along the 35°N latitude circle for the analysis period. Hatched areas represent spectral density greater than $2000(\%)^2 \text{ day}$.

cloud amounts in the frontal zone increased with the approach of the low toward the Baiu front. The influence of the large-scale low on the Baiu front is seen as an increase in the cloud areas around 120°E to 150°E along the 35°N TBB time section of Fig. 12 for Periods 3, 4 and 5, and around 100°E to 120°E in the 30°N time section for Periods 4 and 5.

Synoptic-scale variations are also found in the 500 mb height time sections of Fig. 12. The synoptic-scale variations are more evident in the 35°N and 40°N diagrams. The synoptic-scale cloud systems in the TBB time sections are located in front of the center of the synoptic-scale low. The Baiu front is activated by synoptic-scale lows which propagate from the west in the 30°N – 40°N latitude zone. Cut-off vortexes, troughs and shorter-period variations in the large-scale low fall into this category of synoptic-scale lows. Synoptic-scale lows tend to deepen in the region between 120°E and 150°E . Saito (1985) pointed out that the large-scale quasi-stationary trough formed in the zone between 30°N and 50°N over East Asia during the Baiu season intermittently moved westward. In the present case, the area where synoptic-scale lows deepened moved

gradually from $\sim 150^\circ\text{E}$ in Period 1 to $\sim 120^\circ\text{E}$ in Period 5, as seen in the 35°N and 40°N height-time sections of Fig. 12. This corresponds to the westward movement of the quasi-stationary trough, although it is obscure in the 5-day mean 500 mb height maps (Fig. 4).

6. The mesoscale variations of the Baiu front

In the TBB time sections of Fig. 12, along with the synoptic-scale (about 6-day period) cloud systems, there are variations with a shorter time-scale (*i.e.*, mesoscale), propagating eastward. Fig. 13 shows that one synoptic-scale cloud system is composed of several mesoscale cloud clusters which begin to organize around 130°E . In other words, a synoptic-scale cloud system is sustained for its long lifetime by successive development of new mesoscale cloud clusters which replenish the decay of pre-existing mesoscale cloud clusters. Also, between 90°E and 120°E in the 30°N and 35°N TBB time sections (Fig. 12), variations with a one day period of cloud amounts can be seen superimposed on the synoptic-scale variations. Also, as indicated in Fig. 10 and 11, periods of one to a few days (mesoscale)

Fig. 11. Diagrams of power spectral density of high-cloud amounts (Ch) for periods of 5.86 days (upper), 2.41 days (middle) and 1.00 day (lower). Hatched areas represent spectral density greater than $2000(\%)^2$ day.

are evident in the variation of cloud amounts in the frontal zone. The mesoscale variations will be analysed in detail in this section.

a. The regional characteristics of mesoscale cloud features over the continent, the NW Pacific and the Japan Islands

The difference in the frontal characteristics mentioned in the previous sections also reflect on mesoscale cloud features in the Baiu front. The regional characteristics are discussed below.¹

Over the continent

The width of the Baiu frontal cloud zone, from the TBB time section maps between 95°E and 120°E in Fig. 13, was found to be ~ 500 km. In the zone, areas of lower TBB appear with a one-day period. The minimum TBB is less than -60°C . The hori-

zontal distributions of TBB at each observation time (not shown) demonstrate that the low TBB areas have a diameter of about 500 km and the horizontal gradient of TBB (∇TBB) is very large between the -20°C and -60°C isotherms. These features reveal that mesoscale cloud clusters with diameters of approximately 500 km formed with periods of about one-day in the Baiu frontal zone and the mesoscale clusters consist of cumulonimbus clouds. The cloud features mentioned here are commonly found throughout the analysis period over the continent, although they vary somewhat over the periods and locations (longitude to longitude) as will be noted later (Subsection 6-c).

Over the Northwest Pacific

Mesoscale cloud clusters about 1000 km in diameter are observed in the Baiu frontal cloud zone around 140°E to 165°E . They are aligned along the Baiu front which meanders with the synoptic-scale

¹In this part of the analysis, nephanalysis charts produced operationally four times a day by the Meteorological Satellite Center of JMA are also used.

Fig. 12. Time-longitude sections of TBB (upper) and height at the 500 mb level along the 50°N, 40°N, 35°N, and 30°N latitude circles during the analysis period. The isotherm interval is 20°C. Black areas represent areas of TBB lower than -60°C. The contour interval of the lower figures is 50 gpm. Relatively high areas are striped and relatively low areas are stippled in the lower figures.

Fig. 13-a. Time-latitude sections of TBB along longitudes of 95°E, 100°E, 105°E, 110°E, 115°E (over the continent). The isotherm interval is 20°C. Black areas represent areas of TBB lower than -60°C.

Fig. 13-b. As in 13-a, but for 120°E, 125°E, 130°E, 135°E and 140°E (over the east coast of the continent to the Japan Islands).

Fig. 13-c. As in Fig 13-a, but for 145°E, 150°E, 155°E, 160°E and 165°E (over the northwest Pacific).

period. Their average life time is about a few days. A few mesoscale cloud clusters, as a whole, compose a synoptic-scale cloud system. The minimum TBB in these mesoscale clusters was relatively higher than that in the mesoscale clusters over the continent, and the gradient of the TBB (∇TBB) in the clusters was less. The areas bounded by the TBB -20°C and -40°C isotherms are very large, compared to those over the continent. These features are similar to those of cloud clusters over Japan, which were analysed by Akiyama (1984 a). The wide area with higher TBB and the narrow area with lower TBB in a mesoscale cloud cluster of the present case indicate stratiform and convective cloud areas, respectively. It is a characteristic of the NW Pacific area that the mesoscale cloud clusters consist of narrow convective and wide stratiform cloud areas.

Over the Japan Islands

As pointed out in Section 4, the Baiu front between 120°E and 140°E is a transitional zone. The mesoscale cloud cluster features in this zone also indicate transitional characteristics. That is, the mesoscale cloud clusters at 120°E are relatively small and show a convective nature. The size of the clusters gradually increases toward the east, as the value of the minimum TBB becomes higher and the gradient of the TBB in the clusters decreases. The period of mesoscale variations also changes toward the east, from one day to a few days (see Figs. 10 and 11). These changes in the cloud features of

mesoscale clusters are consistent with changes in the rainfall features over Japan, as noted in Section 3.

Akiyama (1984 a, b) has presented, in a case study of a mesoscale cloud cluster developed in the Baiu front, that the character of the cluster changed from an ensemble of convective clouds over the continent to a cloud system consisting of both convective and stratiform clouds over Japan. The change in the character of the mesoscale cloud clusters from the continent to the NW Pacific in the present case confirms the results of Akiyama (1984 a, b).

b. Mesoscale lows associated with mesoscale cloud clusters

The mesoscale disturbances in the Baiu frontal zone will be examined from low-level height fields, since mesoscale disturbances in the Baiu front are generally confined to the lower layer (e.g., see Ninomiya and Akiyama, 1971). Fig. 14 displays the time changes of 850mb heights for the stations noted in Fig. 1. These stations are located on Lines A, B and C (Fig. 1) which cross the Baiu frontal cloud zone during Period 2 to Period 6. Time sections of Line A represent features of synoptic and mesoscale lows around the coastal region of the continent, while time sections of Lines B and C present those over the Japan Sea and the Pacific sides of Japan. Although Line C is only separated by about 300 km from Line B, the features of 850 mb height changes along Line C are significantly different from those along Line B. In other words, the amplitude and

Fig. 14. Time series of the 850 mb height at the upper stations along Lines A, B and C in Fig 1, during the analysis period.

propagation velocity of both synoptic and meso scale lows in and around the Baiu frontal zone change greatly in both time and space. In Fig. 14, some of significant minimums of the 850 mb heights indicated by broken lines are labelled with I–VIII for description, although it was difficult to identify and trace every minimum as a disturbance.

In the figure for Lines A, B and C, the time changes at the stations located just north of the Baiu front (54662, 47412 and 47420) indicate eastward propagating oscillations of ~ 6 -day period with large amplitudes. They correspond to the propagation of synoptic-scale lows. In Line A (top, Fig. 14), the short period variations of small amplitude, indicated by IV, V and VI are also found. In addition, one-day period variations with very small amplitude are observed at the southern stations on Line A (58238, 58457) during Periods 3 and 4. These short period variations increase in amplitude as they propagate eastward (see Line B). Some of them, however, dissipate around 140°E , as shown in Line C (note the length of the broken lines). The peaks of rainfall in Fig. 2 approximately coincide with height decreases at the stations located on Lines B and C. These height changes with periods of one to a few days are associated with mesoscale cloud clusters which made up synoptic-scale cloud systems. In general, the mesoscale lows tend to generate around 110°E in the Baiu frontal zone, develop around 130°E , and bring heavy rainfall over southwest Japan. The life time of these mesoscale lows is one to a few days. By comparing the frequency appearance of mesoscale lows in the active phase (Periods 3, 4 and 5) with that in the inactive phase (Periods 2 and 6), it can be seen that mesoscale lows tend to develop during the active phase.

Next, the vertical structure of mesoscale lows will be studied by examining the time series data of the 300, 500 and 850 mb heights at stations 47827 and 47412 (Fig. 15). Station 47827 is located in the southern part of the Baiu frontal cloud zone, while 47412 is located 1500 km northeast just north of the frontal zone. In spite of the short distance, the vertical distributions of time changes of heights are different between the two stations. At 47412, the time changes of heights mainly show the variations with a synoptic-scale period, having large amplitudes throughout the troposphere during the analysis period. The amplitude of the variations increases with height. On the other hand, at 47827 mesoscale period variations are evident at the 850 mb level and the amplitude of the mesoscale variations is relatively large in the lower layer, while the height changes at the 300 mb level show synoptic-scale period variations with large amplitude. The development of mesoscale lows tends to be confined to the lower troposphere within the Baiu frontal zone, while synoptic-scale lows are prominent in the

Fig. 15. Time series of height during the analysis period at the 300 mb, 500 mb and 850 mb levels for stations 47412 and 47827.

upper troposphere.

c. The difference of cloud amounts between 00GMT and 12GMT

Difference in large-scale Baiu frontal activity was observed between 00GMT and 12GMT throughout the analysis period (Subsections 4-a and f). Especially, the difference in high-cloud amounts was large over the continent (Figs. 3 and 11). In this section, the difference in mesoscale features of high-cloud amounts between 00GMT and 12GMT will be investigated.

The Baiu frontal cloud zone extended over nearly the same latitudinal zone during Periods 3, 4 and 5 (Fig. 3). Cloud amounts were large throughout these periods (active phases). Therefore, it is suitable to compare the 15-day mean Ch of 00GMT averaged over these periods with that of 12GMT. Large differences of Ch, ($\delta Ch = Ch_{00} - Ch_{12}$) are found over the continent and in the frontal cloud zone in Fig 16. The difference (δCh) reaches 20–30 % with positive and negative areas having widths of 500–1000 km. These features reveal that the one-day period variation in the frontal activity are geographically fixed. The mesoscale areas of positive difference coincide with basins on the topography map of Fig. 16, while the mesoscale areas of negative difference coincide with areas of higher altitude. Over the basins and/or lower altitude

areas (e.g., Szechwan Bas., $\sim 30^\circ N/105^\circ E$; around Nanking, $\sim 32^\circ N/118^\circ E$) cloud amounts were large at 00GMT, while over the mountain areas (e.g., Siensia-Ling Mount. Range, $\sim 28^\circ N/120^\circ E$; Tibet; the Japan Islands) cloud amounts were large at 12GMT (see Fig. 13). From the above facts it is inferred that the topography affects the development of mesoscale cloud clusters in the Baiu front. The geographical features of the underlying surface influence mesoscale variations in the Baiu front through the diurnal change of radiative and/or thermodynamic processes. At present, however, the physical relationships between the facts described in Subsection 4-f (large-scale) and in this subsection are not clear. This is a problem to be studied in future works.

Another interesting features seen in the δCh distribution (Fig. 16) are the alternate appearance of positive maximums (indicated by P) of δCh on the Baiu front at $\sim 35^\circ N/130^\circ E$, $\sim 35^\circ N/145^\circ E$ and $\sim 40^\circ N/160^\circ E$, while negative maximums (indicated by N) of δCh are found on the Baiu front at $\sim 35^\circ N/125^\circ E$, $\sim 35^\circ N/137^\circ E$ and $\sim 35^\circ N/150^\circ E$. It is inferred that some mesoscale variation enhanced by a certain topographical effect propagates eastward, and appears as the maximum δCh at 00GMT and 12GMT. To justify the inference, the eastward movement of mesoscale cloud systems which are generated over a certain area should be traced, using hourly GMS-IR observation data.

7. Remarks

The purpose of this paper was to describe the overall features of space-time variations in the Baiu frontal activity. The analysis period was July 1982, during which the Baiu frontal cloud zone lay along $30^\circ N$ latitude over East Asia and brought heavy rainfall to Japan. The variations of frontal activity were described in large-scale, synoptic-scale and mesoscale aspects, mainly based on GMS-IR data. The time scales of synoptic and mesoscale phenomena were determined from the results of a spectral analysis of the cloud amounts in the Baiu frontal zone. The large-scale features were analysed by examining 5-day mean fields. The analysis period was subdivided into six 5-day periods. The maximum of 5-day mean cloud amounts was defined as the Baiu frontal zone. Periods 2 and 6 were defined as inactive phases of frontal activity, while Periods 3, 4 and 5 were classified as active phases. Attention was focused on the following three subjects; (1) the difference in large-scale features between the active phase and the inactive phase of the Baiu front, (2) the difference in synoptic-scale and mesoscale variations of frontal cloud features between the western part (the continent) and the eastern part (the Northwest Pacific) of the Baiu front, and (3) the difference in frontal activity between 00GMT and 12GMT.

Fig. 16. The upper panel is the difference of 15-day (Periods 3, 4 and 5) mean Ch between 00GMT and 12GMT, $\delta Ch = (Ch_{00} - Ch_{12})$. The isoline interval is 10 %. Areas of negative difference greater than 10 % are stippled. The lower panel is the topography of the domain used for the analysis of GMS data, which was smoothed over areas of 1° latitude by 1° longitude. The regions bounded by dotted and broken lines represent areas of the 15-day mean Ch more than 40 % at 00GMT and 12GMT, respectively. Symbols $\times$ and $\bullet$ represent the positions of positive δCh areas and negative δCh areas, respectively.

The results of the analysis are as follows:

- (1) In large-scale aspects, the active phases of the Baiu front are characterized by a large horizontal gradient of height (∇Z), temperature (∇T) and equivalent potential temperature ($\nabla \theta_e$) with large amounts of moisture flux convergence ($\nabla \cdot q\nu < 0$) in the lower layer of the frontal zone. The moisture flux convergence is mainly due to a strong low-level southerly wind, since the low-level moisture content around and south of the Baiu frontal zone during the active phase is nearly equal to that in the inactive phase.
- (2) In large-scale aspects, the difference between the eastern part (the NW Pacific) and the western part (the continent) of the Baiu frontal zone is found in the air masses and baroclinicity. For the western part, the Baiu front is characterized by relatively weak baroclinicity, low-level horizontal wind shear

and a low-level high θ_e air mass to the south. The eastern part is characterised by baroclinicity (vertical shear) and a relatively low θ_e air mass. (see Table 3)

- (3) The difference in the frontal characteristics between the regions is reflected in synoptic-scale and mesoscale variations in frontal cloud features. Over the continent, synoptic-scale (about six-day period) variations are relatively small and periods of about one day are clearly seen. The mesoscale cloud systems are composed mainly of convective clouds. Over the NW Pacific, synoptic-scale variations are evident, and mesoscale variations with periods of about 3.5 days and 2.5 days are superimposed on them. The mesoscale cloud clusters are composed of narrow convective cloud areas and wide stratiform areas. Around Japan, synoptic-scale and mesoscale variations in the Baiu frontal zone show transitional

Table 3. Regional characteristics of the Baiu frontal zone.

Western part(the continent)	Eastern part (the NW Pacific)
weak baroclinicity	relatively strong baroclinicity
low-level horizontal wind shear	vertical shear
low-level high θ_e air mass	relatively low θ_e air mass

Table 4. Regional characteristics of the cloud variations

	the continent (90°E – 125°E)	Japan (125°E – 140°E)	the NW Pacific (east of about 140°E)
synoptic-scale meanders of the frontal zone	small →	transitional → features	evident
mesoscale periods of 2.5 – 3.5 days, clusters of about 1000 km composed of <u>convective and stratiform clouds</u>	—	transitional features	↗ evident
mesoscale periods of about one day, clusters of about 500 km composed of convective clouds	evident →	—	—

features between the eastern and western parts. (see Table 4)

(4) Synoptic-scale and mesoscale variations are also observed in the time changes of height. The synoptic-scale variations propagate to the Baiu frontal zone and its northern region, from the west to the NW Pacific. In the frontal zone during the active phases over Japan, mesoscale variations are evident in the lower layer, but obscure in the upper layer, while synoptic-scale variations are evident in the upper layer.

(5) Over the continent, the low-level moisture flux south of the Baiu front, the low-level moisture flux convergence and the mid-level moisture content in the Baiu frontal zone are remarkably large at 00GMT compared with 12GMT. In the large-scale sense, cloud amounts are large over the northern part and small in the southern part of the Baiu front at 00GMT as compared with 12GMT. In other words, the Baiu front shifts about 200 km northward at 00GMT. The shift is associated with the changes in wind and moisture flux fields mentioned above.

(6) In the mesoscale sense, cloud amounts are relatively large over basin areas at 00GMT, while they are relatively large over mountain areas at 12GMT. That is, mesoscale variations in cloud amounts in the Baiu frontal zone partly depend on the conditions of the underlying surface.

In Part II of this study, the vertical structure of the Baiu front and the features of synoptic-scale and mesoscale disturbances will be examined by analysing relative vorticity fields.

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1982年7月の梅雨前線の大規模・総観規模および中規模的変動

Part I: 雲変動の様相

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1982年7月の梅雨前線について、大規模的・総観規模的(約6日周期)および中規模的(2~3日以下の周期)変動を総括的に記述する。上記の総観規模および中規模の周期は前線上の雲量をスペクトル解析し決定した。Part Iでは、GMS-IR資料に基づき、(1)梅雨前線の活発な時期(active phase)の大規模場(5日平均場)の特徴、(2)大規模的にみた梅雨前線の東西の相違と前線上の総観規模的・中規模的雲変動の特性、(3)大規模的および中規模的にみた、梅雨前線帯活動における00 GMTと12 GMTの違い、について解析し、以下の事実を見いだした。

(i) active phase(5日平均雲量の多い時期)では、inactive phaseに比し、大規模場の傾圧性(∇T)が強く前線(雲量極大帯)の南側下層で南西~西南西風が強化されている。前線帯での水蒸気フラックスの収束($\nabla \cdot qv < 0$)も大きい。

(ii) 梅雨前線帯の東部(北西太平洋)と西部(中国大陸)では、大規模場の状況が異なり、総観規模的・中規模的雲変動の様相も異なる。下層の強風と高相当温位のairmassで特徴づけられる大陸上の前線では、総観規模周期および約1日周期の変動が卓越する。前線帯の総観規模周期の南北変異は小さい。発達する中規模雲クラスターの大きさは直径約500 km、積雲の集合体である。この約1日周期の変動は、地形との関連が深い。つまり、山地では12 GMTに、盆地・平野部では00 GMTにそれぞれ雲量は増大する。

(iii) 北西太平洋の梅雨前線は、傾圧性および大陸上に比し低い相当温位のairmassで特徴づけられる。前線帯は、総観規模周期で南北に大きく変化し、前線上の中規模積雲クラスターは直径1000 km、2~3日周期で発達する。また同雲クラスターは狭い積雲域および広い層状雲域とで構成されている。日本列島上の前線帯の雲変動は、総観規模的にも中規模的にも、東部と西部での状況の中間的・過渡期的な様相を示す。

(iv) 大陸上の梅雨前線 (110 ~ 120 E) の雲帯は、00 GMT に、12 GMT の位置より北へ約 200 km 移動する。この時 (00 GMT)、下層の風速、水蒸気フラックス、前線内での水蒸気フラックスの収束、および、中層の水蒸気量が、12 GMT に比し増加している。

Part II では、active phase の前線帯の構造、および梅雨前線上の総観規模・中規模擾乱の特性を、相対渦度場で解析する。